NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE 3610

COMPARISON OF LANDING-IMPACT VELOCITIES OF FIRST AND SECOND WHEEL TO CONTACT FROM STATISTICAL MEASUREMENTS OF TRANSPORT AIRPLANE LANDINGS

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Washington
February 1956

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SUMMARY

A statistical analysis of vertical velocities at second wheel to touch was made from photographs of 353 landings of transport airplanes at Washington National Airport. The effects of gusts, rolling direction, and number of engines are presented. Comparisons are made with vertical velocities of the first wheel to touch (NACA TN 3194).

The results of the statistical analysis indicated that the probability of equaling or exceeding a given high value of vertical velocity was slightly greater in any given landing for the second wheel than for the first wheel to contact. Gusty wind conditions had the effect of increasing the vertical velocities for both the first and second wheels to contact. The effect of the direction of rolling was such that the probability of equaling or exceeding a given high value of vertical velocity was greater for the wheel toward which the airplane was rolling just prior to initial impact. There appeared to be no correlation between the relative vertical velocities of first and second wheels to contact and the ratio of wheel tread to radius of gyration such as would be expected from theoretical considerations.

INTRODUCTION

In reference 1 statistical information was presented on vertical velocities, forward speeds, roll angles, and rolling velocities for the first wheel to contact during landings of transport airplanes in routine daytime operations at the Washington National Airport. This information was obtained by photographing the landings with a specially built motion-picture camera. Theoretical calculations of reference 2 indicated that under some conditions the vertical velocity for the second wheel to touch may be higher than for the first wheel. The photographic records obtained in the investigations of reference 1 were reevaluated to obtain these data. Since the photographic records were terminated shortly after the first wheel contacted the runway, records of the second wheel to touch were not always obtained. In fact, in only 353 of the 478 landings reported was the second wheel to contact in the picture; and of these 353 landings, only 312 had the velocities of the first and second wheel to contact and the rolling direction at first contact available simultaneously. Rolling velocities or roll angles could not be obtained for the second wheel to contact since, in a considerable number of cases, the first wheel to touch was still in contact with the ground. Hence, possible oleo strut deflections prevented the determination of these angular parameters. The horizontal velocities for the second wheel to touch were about the same as those of the first wheel to touch. The statistical data on horizontal velocities for the first wheel to touch can be found in reference 1. The purpose of this investigation is to present the statistical information on the vertical velocity of the second wheel to touch and to compare these data with those for the first wheel to touch.

SYMBOLS

y_t/k_X	ratio of semitread to rolling radius of gyration
V	vertical velocity, ft/sec
α_3	skewness factor
σ	standard deviation, ft/sec
p	rolling velocity, deg/sec
ϕ	roll angle, deg

Subscripts:

1	first-wheel-contact condition
2	second-wheel-contact condition

APPARATUS AND METHOD

The 35-millimeter motion-picture camera with which statistical data of the landings were obtained is shown in figure 1. The shutter speed was 1/600 second and the film speed was 25 frames per second. The camera had a 40-inch-focal-length lens and was mounted on a plate which could swivel only in azimuth. The swivel post was rigidly and permanently attached to a trailer frame. Each corner of the trailer frame was supported by a jack that permitted adjustment of the vertical angle of the lens optical axis. By means of these jacks and screw attachments on the lens barrel, the lens optical axis could be accurately leveled at all points of the camera traverse.

Statistical data were obtained from landings of the transport airplanes for which general specification information is given in table I. All data in the present analysis were obtained from landings on runway 33 at the Washington National Airport. The camera was located 800 feet from the center line of the runway in line with the region on the runway at which the greatest number of touchdowns were evidenced by the concentration of tire marks upon the runway surface.

Values of vertical velocities were determined by measuring the vertical distance through which the wheel image moved in the time interval of the five motion-picture frames immediately prior to second-wheel contact, which is equivalent to 4/25 second. Corrections were applied to the results to account for the distance from the image to the lens optical axis, and the distance from the camera to the airplane wheel. Complete descriptions of these corrections and the formulas used are available in reference 3. With the corrections applied to the results, the probable error of the vertical velocity is conservatively estimated to be within ±0.30 foot per second.

PRESENTATION OF RESULTS

The overall results of the statistical analysis combining all flight conditions and airplane types are presented in figure 2 as frequency distributions of the vertical velocities V_1 and V_2 of the first and second wheels to contact, in figure 3 as a frequency distribution of the difference in velocities $V_2 - V_1$, and in figure 4 as probability curves for V_1 and V_2. Other pertinent results are given in table II. The probability data were reduced to Pearson type III curves with the aid of charts presented in reference 4. The experimental probabilities are shown in figure 4 (and subsequent figures) for the same class intervals that were used in the corresponding frequency-distribution curves to indicate the fit of the Pearson curves to the data.

The effect of gusts on vertical velocities is shown in figures 5 and 6. The presence of gusts at the time that the landings were photographed was determined from airport hourly weather reports. The definition of gustiness as used herein is in accordance with the criteria of reference 5, which defines gusts as sudden, intermittent increases in wind speed with at least a 10-mile-per-hour (9-knot) variation between peaks and lulls. The peaks must reach at least 18 miles per hour (16 knots) and the average time interval between peaks and lulls should usually not exceed 20 seconds.

The effect of the direction of rolling velocity at the time of the first wheel to contact on the vertical velocities V_1 and V_2 is shown in figures 7 and 8. Rolling is labeled in the figures and table II as positive (+) when the airplane is rolling toward the first wheel to contact and negative (-) when the airplane is rolling away from the first wheel to contact.

Presented in figure 9 is a comparison of the vertical-velocity probability curves obtained from the measured data for the first- and second-wheel contacts, separated into four-engine- and two-engine-airplane categories. This separation was made because theoretical considerations (ref. 2) indicated that the ratio y_t/k_X has a substantial effect on the relative severity of the impact velocity of the first and second wheels to contact in landing. The values of the ratio y_t/k_X of 0.7 to 0.8 for the four-engine airplanes are appreciably different from the values of 1.0 to 1.2 for the two-engine airplanes.

A tabulation of the statistical data used in this paper is given in table III.

DISCUSSION

The results of figure 4 indicate somewhat higher vertical velocities for the second wheel to contact than for the first wheel. For example, for a probability of 0.001 the vertical velocity for the first-wheel contact is 4.5 feet per second, while for the second-wheel contact it is 5.2 feet per second. The average vertical velocity, however, was practically the same (about 1.4 ft/sec) for each wheel (fig. 2).

Gusty wind conditions had the effect of increasing the vertical velocities for the second wheel to contact (fig. 5). This result was also found in reference 1 for the first wheel to contact. The results for both gusty and nongusty wind conditions (fig. 6) indicate that, as before, higher vertical velocities occur for the second wheel to contact than for the first wheel. For example, for a probability of 0.001 the vertical velocities are 4.9 feet per second and 3.7 feet per second for gusty and nongusty wind conditions, respectively, for the first wheel to contact, and about 5.5 feet per second and 4.1 feet per second for gusty and nongusty wind conditions for the second wheel to contact. The average value for V_1 and the average for V_2 were about the same in gusty wind conditions (1.5 ft/sec) and also in nongusty wind conditions (1.2 ft/sec). (See table II.)

A factor affecting vertical velocities at second-wheel contact is the direction of rolling at first-wheel contact (fig. 7). When the airplanes are rolling toward the first wheel to contact, the average value for V_2 (1.30 ft/sec) is appreciably less than for V_1 (1.64 ft/sec). With the airplane rolling away from the first wheel to contact, the average value for V_2 (1.53 ft/sec) is appreciably higher than for V_1 (1.20 ft/sec). The probability of exceeding a given high value of velocity is also higher for the first wheel than for the second wheel with positive roll, but with negative roll it is lower for the first wheel than for the second (fig. 8). For instance, the probability of exceeding a velocity of 4 feet per second is about 0.0046 for the second wheel and about 0.0058 for the first wheel with positive roll, and about 0.0084 for the second wheel and 0.0025 for the first wheel with negative roll.

From the statistical data shown in table II and figure 9, there appears to be no definite correlation associated with the factor y_t/k_X. The average vertical velocity is about the same for first or second wheel to contact for the two-engine airplanes and somewhat higher for the first wheel than the second for the four-engine airplanes. In both cases, however, the probability of equaling or exceeding a given high value of vertical velocity tended to be somewhat greater for the second wheel to contact than for the first. Apparently, the effect of the differences in y_t/k_X is masked by other factors such as bank angles and rolling velocities at initial contact, side drift, landing-gear energy-dissipation efficiency, and so forth.

CONCLUSIONS

A statistical analysis of the contact conditions of the second wheel to contact of 353 transport airplane landings in routine daytime operations has been made. This study has led to the following conclusions:

1. The probability of equaling or exceeding a given high value of vertical velocity was somewhat greater in any given landing for the second wheel than for the first wheel to contact.

2. Gusty wind conditions had the effect of increasing the velocities for both the first and second wheels to contact.

3. The effect of the direction of rolling was such that the probability of equaling or exceeding a given high value of vertical velocity was greater for the wheel toward which the airplane was rolling just prior to initial impact.

4. There appeared to be no correlation between the relative vertical velocities of first and second wheels to contact and the ratio of wheel tread to radius of gyration such as would be expected from theoretical considerations.

Langley Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., October 25, 1955.

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TABLE I

GENERAL SPECIFICATION DATA FOR TRANSPORT AIRPLANES

Airplane	Number of engines	Maximum gross weight, lb	Wing area, sq ft	Maximum wing loading, lb/sq ft	Maximum permissible landing weight, lb	Main-axle wheel tread, ft	Maximum lift coefficient, landing condition	y_t/k_X
A	Two engine	17,500	545	32.0	15,000	15	2.12	----
B	Two engine	27,000	988	27.3	25,000	18.5	1.96	1.01
C	Two engine	31,000	970	32.0	29,000	18.5	2.04	----
D	Two engine	45,000	1,360	33.0	45,000	26	2.29	----
E	Two engine	42,750	906	47.2	42,000	25	2.78	----
F	Four engine	73,000	1,463	49.8	63,500	26	2.42	----
G	Two engine	41,790	817	51.1	39,800	25.5	2.36	1.18
H	Four engine	107,000	1,650	64.9	85,500	28	2.54	.73
I	Four engine	120,000	1,650	72.7	98,000	28	2.54	----
J*	Four engine	88,000	1,463	60.0	75,000	26	2.57	.68
J*	Four engine	103,000	1,463	70.4	88,000	26	2.60	----
K	Four engine	142,500	1,769	80.5	121,700	28.5	2.42	.74

*Same type of plane - different allowable loads.

TABLE II

VALUES OF STATISTICAL PARAMETERS FOR LANDING CONTACT CONDITIONS

Condition	Wheel to contact	Number of landings	Maximum vertical velocity, V_{max}, ft/sec	Average vertical velocity, V_{av}, ft/sec	Standard deviation, σ, ft/sec	Skewness factor, α_3
Classified according to gust condition						
Total	Second First	353 420	4.99 4.5	1.37 1.44	0.81 .75	1.09 .70
Gusty	Second First	206 232	4.99 4.5	1.53 1.57	.87 .80	1.01 .75
Nongusty	Second First	147 188	3.37 3.4	1.16 1.27	.68 .64	.96 .47
Classified according to number of engines						
Two engine	Second First	180 180	4.49 4.03	1.46 1.46	0.81 .76	0.88 .82
Four engine	Second First	132 132	4.37 4.56	1.31 1.50	.82 .75	.90 .67
Classified according to direction of roll						
Total roll (+)	Second First	194 194	4.37 4.56	1.30 1.64	0.78 .73	0.90 .82
Total roll (-)	Second First	118 118	4.49 4.03	1.53 1.20	.90 .70	.42 1.04
Total	Second First	312 312	4.49 4.56	1.40 1.47	.82 .76	.84 .77

TABLE III.- TABULATION OF DATA

Landing number	Airplane type	V_1, ft/sec	V_2, ft/sec	ϕ_1, deg	P_1, deg/sec	Gusty	Nongusty
4	B	2.90	2.49	—	—	—	x
8	A	1.49	.44	0	1.6	—	x
9	E	1.02	.56	-.9	.6	—	x
11	E	1.37	1.44	-1.0	.4	—	x
14	G	1.12	1.01	-2.7	.4	—	x
20	A	.72	2.25	-2.7	2.7	x	—
21	F	1.33	.77	-1.3	-.4	x	—
22	G	2.26	.70	—	—	x	—
23	B	—	1.99	—	—	x	—
24	G	1.63	2.40	-5.5	-.8	x	—
26	F	1.14	1.20	1.5	1.7	x	—
27	E	1.37	1.64	-1.7	-.6	x	—
29	E	2.33	1.31	-1.8	1.3	x	—
30	G	1.46	1.23	—	—	x	—
31	E	2.01	2.12	-1.4	.1	x	—
34	E	3.62	3.67	1.2	2.6	x	—
35	G	1.23	.26	-1.1	1.3	x	—
38	J	—	1.33	—	—	x	—
39	E	—	1.15	—	—	x	—
45	J	.47	.68	-1.2	.5	x	—
46	F	1.54	1.43	2.0	.8	x	—
49	G	1.88	2.52	.6	2.0	x	—
50	G	1.10	.09	-1.1	.6	x	—
51	E	1.41	1.74	—	—	—	x
53	J	1.27	.21	-.6	.2	—	x
54	G	1.25	1.78	-.6	.8	—	x
55	E	1.85	.97	-.1	2.6	—	x
56	H	2.24	1.28	-1.4	1.2	—	x
58	F	.77	.77	-.2	-1.1	—	x
61	E	.38	1.97	1.4	-.8	—	x
62	H	2.44	2.28	-.3	.3	—	x
65	A	1.93	1.64	0	1.0	—	x
70	G	1.12	.47	1.0	0	—	x
72	H	—	.81	—	—	—	x
74	E	.63	.97	-.2	-.9	—	x
77	A	1.10	1.02	.2	1.5	—	x
81	G	1.59	1.82	.3	-.5	—	x
82	B	.58	.49	.7	-1.2	—	x
85	E	.89	.59	-.4	-.1	—	x
94	G	1.80	1.85	.4	-1.0	x	—
95	J	2.76	2.76	.3	.1	x	—
97	J	.43	.89	-.3	1.4	x	—
99	B	—	1.02	—	—	x	—
100	G	—	2.51	—	—	x	—
101	J	1.72	2.08	-.1	-.6	x	—
102	J	2.02	.51	-1.7	.3	x	—
112	B	.48	1.41	-1.1	-2.1	x	—
115	E	1.71	1.52	-.2	.4	x	—
120	G	2.60	1.70	-1.2	1.3	x	—
121	G	1.76	1.11	-2.0	1.5	x	—
122	J	2.19	.79	-2.3	.3	x	—
124	G	.71	1.68	-.8	-1.2	x	—
130	J	1.73	.14	-1.4	.5	x	—
132	G	2.08	1.16	-3.2	2.3	x	—
134	E	1.93	2.26	.1	-.7	x	—
135	G	1.81	1.95	-1.8	2.2	x	—
138	I	2.53	1.37	-1.1	2.8	x	—
140	G	2.24	1.99	-.4	.9	x	—
142	B	1.56	1.09	-.3	1.5	—	x
145	E	.72	.63	-.1	1.2	—	x
148	F	1.69	.21	-1.1	1.2	—	x
149	F	.35	.84	.5	-1.1	—	x
150	B	.80	.80	-.6	2.8	—	x
153	B	.99	1.39	.9	0	—	x
157	E	.93	.53	.4	1.5	—	x
158	E	2.45	2.31	.6	.3	—	x
159	H	2.25	.81	-.8	1.9	—	x
162	J	—	.98	—	—	—	x
163	E	1.70	1.72	-1.6	-.2	—	x
164	B	1.08	.09	—	-1.4	—	x
169	J	1.47	.92	-.9	1.9	—	x
170	G	1.21	1.17	-.3	.1	—	x
172	G	1.94	2.69	-.3	-1.6	—	x
176	B	.68	1.27	-1.3	.9	—	x
178	G	1.81	1.14	—	—	—	x

TABLE III.- TABULATION OF DATA - Continued

Landing number	Airplane type	V_1, ft/sec	V_2, ft/sec	ϕ_1, deg	p_1, deg/sec	Gusty	Nongusty
181	B	1.85	1.86	-1.0	-0.5	—	x
184	G	.18	1.13	—	—	—	x
185	I	.82	1.68	.2	-1.8	—	x
186	F	1.07	.20	-1.4	-.3	—	x
187	B	.60	.39	-.6	1.9	—	x
189	F	1.29	.47	-.1	.6	—	x
190	A	1.33	.72	1.4	1.2	—	x
191	F	1.69	1.14	-1.0	.2	—	x
194	G	2.05	1.01	-2.9	.8	—	x
199	H	3.10	1.92	3.9	2.6	x	—
205	J	1.22	.79	—	-.8	x	—
206	F	—	.69	—	—	x	—
207	B	.81	1.02	.4	-.1	x	—
211	H	.40	.51	-.6	-.2	x	—
212	F	.33	.59	-.4	.9	x	—
215	G	1.59	1.59	-.3	.4	x	—
216	E	—	.75	—	—	x	—
217	H	1.78	2.53	-.3	-2.0	x	—
218	E	1.48	1.57	-1.1	1.8	x	—
219	F	1.56	.38	1.1	-.4	x	—
220	E	1.86	1.82	-.7	.1	x	—
225	E	3.90	3.77	-2.1	1.1	x	—
226	E	2.96	1.43	-2.5	1.9	x	—
229	J	—	1.70	—	—	x	—
232	G	2.09	1.74	-3.4	1.0	x	—
233	J	—	.85	—	—	x	—
234	J	2.16	1.87	-3.6	1.7	x	—
236	F	—	2.08	—	—	x	—
240	F	1.18	1.35	-1.8	.4	x	—
241	G	—	2.61	—	—	x	—
245	F	1.95	2.27	-2.1	.3	x	—
246	E	.42	.77	-2.3	-1.5	x	—
247	I	1.86	1.31	-3.3	.2	x	—
248	G	1.34	3.10	-3.7	-2.6	x	—
252	G	2.06	1.39	.7	.8	—	x
253	F	.41	.54	-.9	-.3	—	x
254	J	2.44	2.23	-.2	.5	—	x
255	F	1.76	1.19	.1	.8	—	x
256	J	.54	.83	-.5	-.5	—	x
259	J	1.98	.70	-1.3	1.0	—	x
261	G	.35	.91	.2	-1.9	—	x
263	J	2.29	1.96	-.2	.7	—	x
264	E	2.21	1.52	1.0	1.3	—	x
265	E	3.38	3.37	-3.2	.1	—	x
266	J	2.46	2.41	.2	-.2	—	x
267	F	1.23	1.33	-.5	-.2	—	x
268	E	.55	1.20	-1.3	0	—	x
270	H	.64	1.17	-1.2	-1.8	—	x
271	H	.78	.23	-.5	1.1	—	x
275	F	1.40	1.44	-1.2	.3	—	x
278	H	1.92	1.45	-1.1	.4	—	x
280	B	—	1.70	—	—	—	x
282	E	2.86	1.43	-1.1	2.3	—	x
283	A	1.72	1.72	-1.4	1.5	—	x
284	E	1.02	.93	.8	.4	—	x
286	F	1.08	.57	-1.8	-.5	—	x
290	G	.40	1.09	-1.2	-2.0	—	x
296	B	—	.96	—	—	—	x
298	G	—	1.63	—	—	—	x
299	B	—	.15	—	—	x	—
300	H	1.43	.80	1.5	.6	x	—
301	E	1.08	.93	2.6	.2	x	—
304	E	2.84	2.89	-.5	.1	x	—
305	B	1.66	.55	-2.8	-1.3	x	—
306	G	2.53	1.92	-2.9	.6	x	—
307	J	1.96	1.76	0	.4	x	—
309	B	.76	1.26	-.4	-1.6	x	—
310	E	1.95	1.23	-.2	-1.7	x	—
311	H	2.28	.81	-1.4	2.0	x	—
313	E	1.21	.62	-1.7	2.4	x	—
314	J	1.45	1.71	-.5	.1	x	—
315	J	2.97	2.97	.1	.4	x	—
316	E	2.12	1.60	-1.6	1.6	x	—
317	J	.95	.39	-.6	.7	x	—
318	A	.44	1.07	-.5	-2.3	x	—

TABLE III.- TABULATION OF DATA - Continued

Landing number	Airplane type	V_1, ft/sec	V_2, ft/sec	ϕ_1, deg	p_1, deg/sec	Gusty	Nongusty
319	E	2.37	2.03	-0.3	0.8	x	—
320	H	.97	.82	-.6	-1.6	x	—
321	H	1.37	1.58	-.3	1.5	x	—
322	G	1.53	1.46	-.1	.7	x	—
323	G	2.22	2.54	1.9	.3	x	—
326	B	1.11	.66	-1.3	1.6	x	—
328	B	1.11	1.62	-1.9	1.3	x	—
329	F	.68	.05	1.2	1.4	—	x
331	G	.88	1.91	-1.4	0	—	x
332	I	1.98	3.14	.6	-1.9	—	x
333	J	.45	.55	.3	.3	—	x
336	F	1.91	.84	-1.9	2.1	—	x
337	G	1.50	1.50	-.1	-.4	—	x
338	G	1.30	1.16	-2.1	-.6	—	x
339	F	1.21	.84	.4	1.0	—	x
340	B	1.34	.68	-2.8	2.6	—	x
341	G	1.29	1.12	-2.1	-.6	—	x
342	E	1.43	2.77	-.9	-3.1	—	x
343	E	1.43	2.19	-1.5	-1.6	—	x
344	F	3.04	2.78	-.9	.2	—	x
346	F	1.67	.93	0	1.5	—	x
348	G	1.57	3.17	-1.5	-1.9	—	x
349	B	1.93	1.82	-2.3	2.5	—	x
354	J	1.09	1.64	1.6	-.2	x	—
355	E	2.12	2.76	-2.8	2.1	x	—
357	B	1.36	.56	.4	1.6	x	—
360	H	1.91	3.48	-.6	-2.7	x	—
361	F	2.93	2.99	-.9	-.9	x	—
363	J	2.52	.26	-1.1	2.3	x	—
364	E	2.22	1.15	-.2	-2.4	x	—
365	G	.82	1.76	-1.5	-1.4	x	—
369	H	4.56	4.37	-.9	.4	x	—
370	G	.61	.85	-.9	-1.3	x	—
372	G	1.06	1.21	1.4	0	x	—
373	G	1.36	1.32	.3	1.4	x	—
375	E	.64	.90	-.1	-.6	x	—
376	J	1.45	1.40	-1.2	.1	x	—
377	G	.64	2.34	2.0	-.3	x	—
378	G	.95	1.35	-2.4	-1.1	x	—
379	F	2.33	2.33	-.1	.2	x	—
381	E	3.17	2.73	-1.3	1.5	x	—
382	B	1.36	1.08	.2	2.0	x	—
384	F	2.03	2.51	-.6	-1.1	x	—
386	B	1.65	.64	-2.0	.5	x	—
387	J	.01	.97	-1.6	-.1	x	—
388	J	——	1.11	——	——	x	—
389	G	2.52	3.31	-.8	-.1	x	—
390	F	1.37	1.58	-.5	-.5	x	—
391	E	1.09	.94	-.2	.3	x	—
393	E	1.78	1.57	-.8	.4	x	—
395	F	2.19	.97	-1.4	.1	x	—
396	E	2.67	2.72	-.8	-.1	x	—
397	H	.72	1.79	-1.8	1.7	x	—
398	E	.16	1.06	-1.1	-.9	x	—
399	J	1.24	1.08	-.5	.4	x	—
400	J	1.71	2.43	.3	-1.3	x	—
401	J	1.49	1.61	-2.2	-.4	x	—
402	E	1.21	.73	-1.6	-.3	x	—
403	H	1.17	1.42	-1.4	-.4	x	—
404	H	1.13	1.81	-.8	-.4	x	—
407	G	1.22	.97	-2.1	.1	—	x
409	F	2.04	1.77	-.9	.1	—	x
411	J	2.15	.27	-.6	.7	—	x
412	G	1.81	1.00	.7	3.0	—	x
413	C	1.08	.81	-.6	.9	—	x
415	E	1.39	1.72	-1.7	.6	—	x
416	G	.62	1.45	-1.8	.3	—	x
417	I	.77	.28	-.6	.3	—	x
418	F	.82	1.07	-1.9	.3	—	x
419	A	.81	.33	-2.9	.4	—	x
420	E	2.00	1.06	-.1	1.9	—	x
423	G	2.37	1.40	-.7	2.9	—	x
425	G	.41	.89	-3.7	-2.3	—	x
429	B	.57	.42	-.6	.5	—	x
431	F	1.49	.44	-1.1	.6	—	x

TABLE III.- TABULATION OF DATA - Continued

Landing number	Airplane type	V_1, ft/sec	V_2, ft/sec	ϕ_1, deg	p_1, deg/sec	Gusty	Nongusty
432	B	0.67	1.77	-1.7	-1.7	x	---
433	J	1.96	2.02	-.2	-.2	x	---
434	E	1.49	1.57	-.2	-.2	x	---
435	F	1.40	.93	.9	2.0	x	---
436	F	.89	1.76	-2.6	-1.9	x	---
437	B	1.61	.99	-2.6	2.5	x	---
438	B	1.91	1.55	-1.0	1.4	x	---
440	J	2.19	1.90	-3.0	2.3	x	---
441	J	1.78	1.55	-1.0	1.2	x	---
442	G	.73	2.31	-.2	-3.6	x	---
444	B	.79	1.09	-1.8	2.1	x	---
445	G	3.07	1.70	-3.1	1.9	x	---
446	F	.61	.72	-.2	-.2	x	---
448	J	---	1.53	---	---	x	---
449	E	1.59	1.28	-.4	.8	x	---
450	E	1.33	1.54	.4	-.3	x	---
451	G	.05	.72	-.7	0	x	---
452	H	2.27	2.27	0	.2	x	---
453	B	2.57	.86	-3.5	3.9	x	---
455	H	.92	1.11	-.4	.1	x	---
456	A	1.00	.47	.4	1.4	x	---
458	J	1.20	1.65	-.5	.4	x	---
459	I	1.18	1.89	-1.6	.7	x	---
460	G	1.22	3.00	-1.0	-2.0	x	---
465	J	1.38	.30	-.5	2.3	x	---
466	G	---	4.99	---	---	x	---
468	J	.90	.25	1.4	.2	x	---
469	F	1.06	1.95	-.7	-2.0	x	---
470	G	.91	1.26	-.9	-.8	x	---
472	E	2.82	2.55	-1.0	.8	x	---
475	B	.92	.84	-.9	.5	x	---
479	E	3.49	3.26	-.7	.5	x	---
480	G	.95	1.12	.5	1.5	x	---
481	E	2.35	1.91	-.1	1.0	x	---
482	F	1.00	1.57	-.9	-1.2	x	---
485	J	.02	.14	-1.2	-.1	x	---
486	E	1.62	1.85	-.3	-.5	x	---
488	J	2.48	2.48	.1	-1.7	x	---
490	J	1.78	1.47	-.3	.7	x	---
491	H	1.08	1.58	.4	-2.3	x	---
492	F	.66	.01	.4	-.4	x	---
493	F	1.55	1.79	-.4	-.5	x	---
494	B	.83	.85	1.1	0	---	x
496	E	.45	1.03	-.2	-.6	---	x
498	F	.55	1.18	-1.0	.3	---	x
499	B	1.50	.81	-1.5	-.8	---	x
500	E	2.01	1.56	-2.1	1.5	---	x
501	J	.37	.26	-.4	.6	---	x
502	H	.90	.44	.4	-.6	---	x
503	E	2.00	2.32	-.9	1.3	---	x
504	J	.70	.45	-1.0	.3	---	x
506	E	.41	1.18	-.1	-1.8	---	x
507	H	.83	.71	2.3	-1.1	---	x
508	G	.58	.45	-1.1	-.5	---	x
509	B	.68	.56	0	.4	---	x
510	J	1.10	1.88	.1	0	---	x
511	G	1.00	.45	-.9	.4	---	x
512	G	1.86	1.79	-1.0	.4	---	x
513	H	1.89	.96	-1.6	.3	---	x
514	K	.88	1.30	1.2	-.7	---	x
515	J	1.52	.68	-.3	.4	---	x
516	B	.56	.44	.1	.4	---	x
519	G	1.13	.94	.7	.8	---	x
521	I	.68	1.00	1.0	-1.2	---	x
522	B	---	.45	---	---	---	x
523	B	1.67	1.39	-.4	.9	---	x
524	J	1.36	.61	-.7	.4	---	x
525	F	.94	1.12	.3	-1.0	---	x
526	G	.84	1.20	-.5	-.8	---	x
527	E	1.40	1.66	.5	.2	---	x
528	A	1.24	.96	-.7	1.0	---	x
529	E	1.48	1.69	-1.0	-.2	---	x
530	G	1.81	1.53	1.2	.2	---	x
531	G	1.05	.87	-.9	-.6	---	x
532	B	.98	.97	-.2	.1	---	x

TABLE III.- TABULATION OF DATA - Concluded

Landing number	Airplane type	V_1, ft/sec	V_2, ft/sec	ϕ_1, deg	p_1, deg/sec	Gusty	Nongusty
533	F	1.37	1.08	-0.7	0.4	---	x
534	F	1.68	1.80	.8	-.4	---	x
535	A	.08	.72	-.5	-2.3	---	x
536	E	2.55	2.84	-1.2	-.4	---	x
537	A	1.90	2.14	0	.2	---	x
540	F	.95	.18	-1.3	-.6	---	x
541	J	1.23	1.54	1.2	.2	---	x
545	F	-.97	.94	-.6	.1	---	x
550	F	.36	.60	-.2	-.5	---	x
551	G	----	1.04	----	----	---	x
553	A	----	1.08	----	----	---	x
556	A	1.91	2.18	-1.9	4.7	x	---
561	F	1.87	3.66	-4.2	-2.5	x	---
564	J	1.69	1.09	-.4	1.3	x	---
565	H	3.34	2.84	-.4	1.0	x	---
570	G	.65	.51	-2.0	-2.1	x	---
575	G	.73	1.11	.2	1.5	x	---
577	F	----	.48	----	----	x	---
578	J	1.36	2.72	.3	-3.0	x	---
581	B	----	.91	----	----	x	---
583	E	----	.95	----	----	x	---
585	I	2.54	1.13	-2.0	2.3	x	---
587	J	2.70	1.13	-1.8	2.0	x	---
589	H	2.21	2.21	-.1	.4	x	---
590	A	1.07	1.65	-3.8	2.8	x	---
592	B	.64	.28	-2.2	1.2	x	---
593	E	2.29	1.37	-.5	2.4	x	---
594	G	1.43	.47	-2.2	0	x	---
595	F	----	.39	----	----	x	---
597	G	----	1.45	----	----	x	---
600	G	1.21	2.44	-2.4	2.7	x	---
602	E	1.09	2.86	-3.4	3.8	x	---
603	E	----	1.31	----	----	x	---
604	G	.77	.87	-.3	-.2	x	---
605	F	1.74	1.43	-2.9	0	x	---
606	F	----	.51	----	----	x	---
608	D	1.31	.09	-2.9	1.7	x	---
611	F	----	.28	----	----	x	---
612	B	.51	2.42	-2.8	-4.4	x	---
615	B	----	.58	----	----	x	---
616	F	.76	1.22	-1.2	.6	x	---
617	G	.82	2.69	-.2	-.9	x	---
618	E	2.52	2.85	.1	-.8	x	---
620	F	1.45	.57	.5	1.6	x	---
622	E	4.03	4.49	-2.3	-1.7	x	---
623	G	----	2.58	----	----	x	---
624	G	2.00	2.46	0	-1.0	x	---
625	J	2.10	1.53	-1.4	.1	x	---
627	G	1.55	.83	-5.7	1.7	x	---
628	F	----	.97	----	----	x	---
633	B	----	.40	----	----	x	---
634	B	.51	.87	-1.3	-.8	x	---
638	E	2.54	1.77	-1.7	-.2	x	---

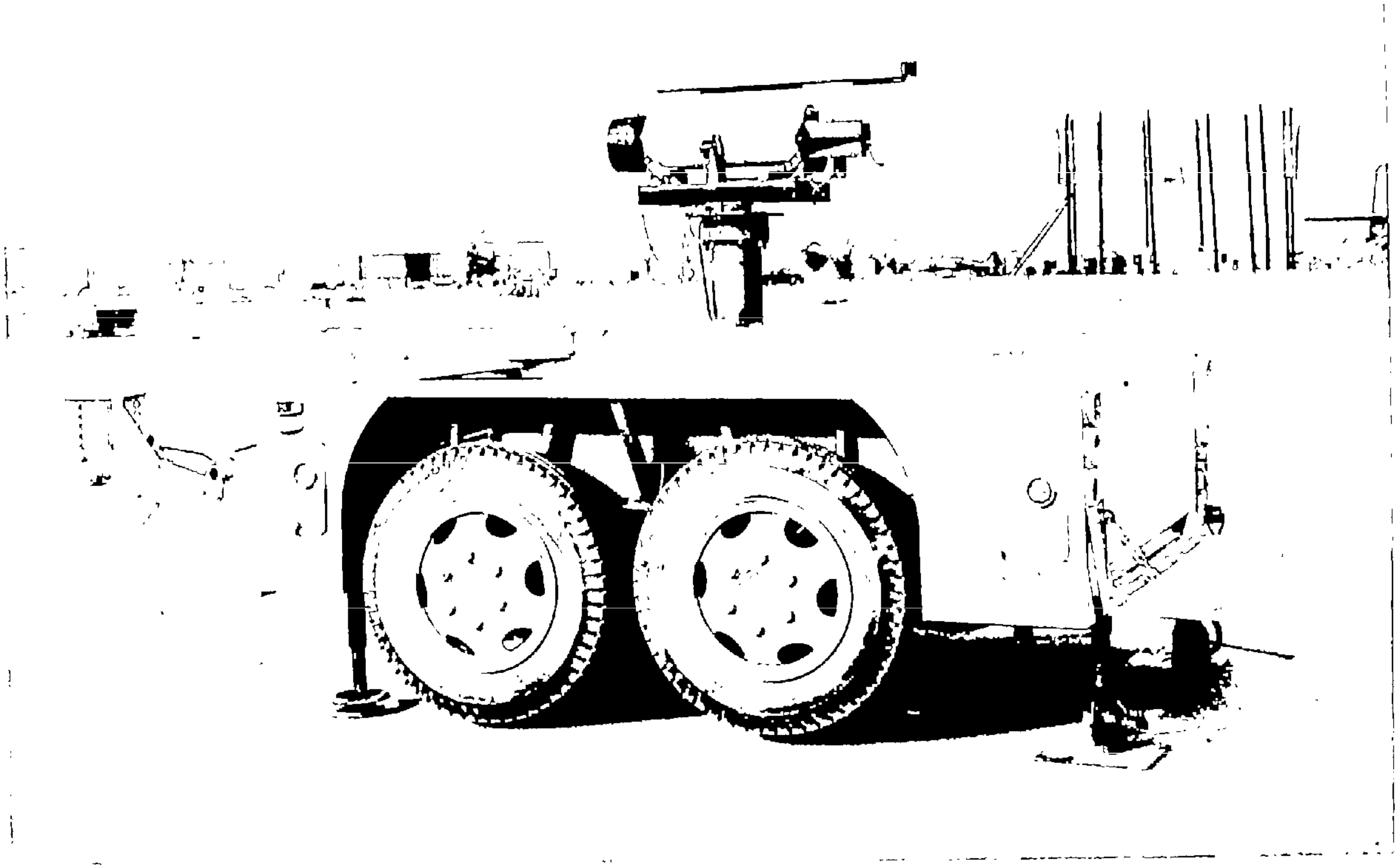

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Figure 1.- Equipment for measuring landing contact conditions.

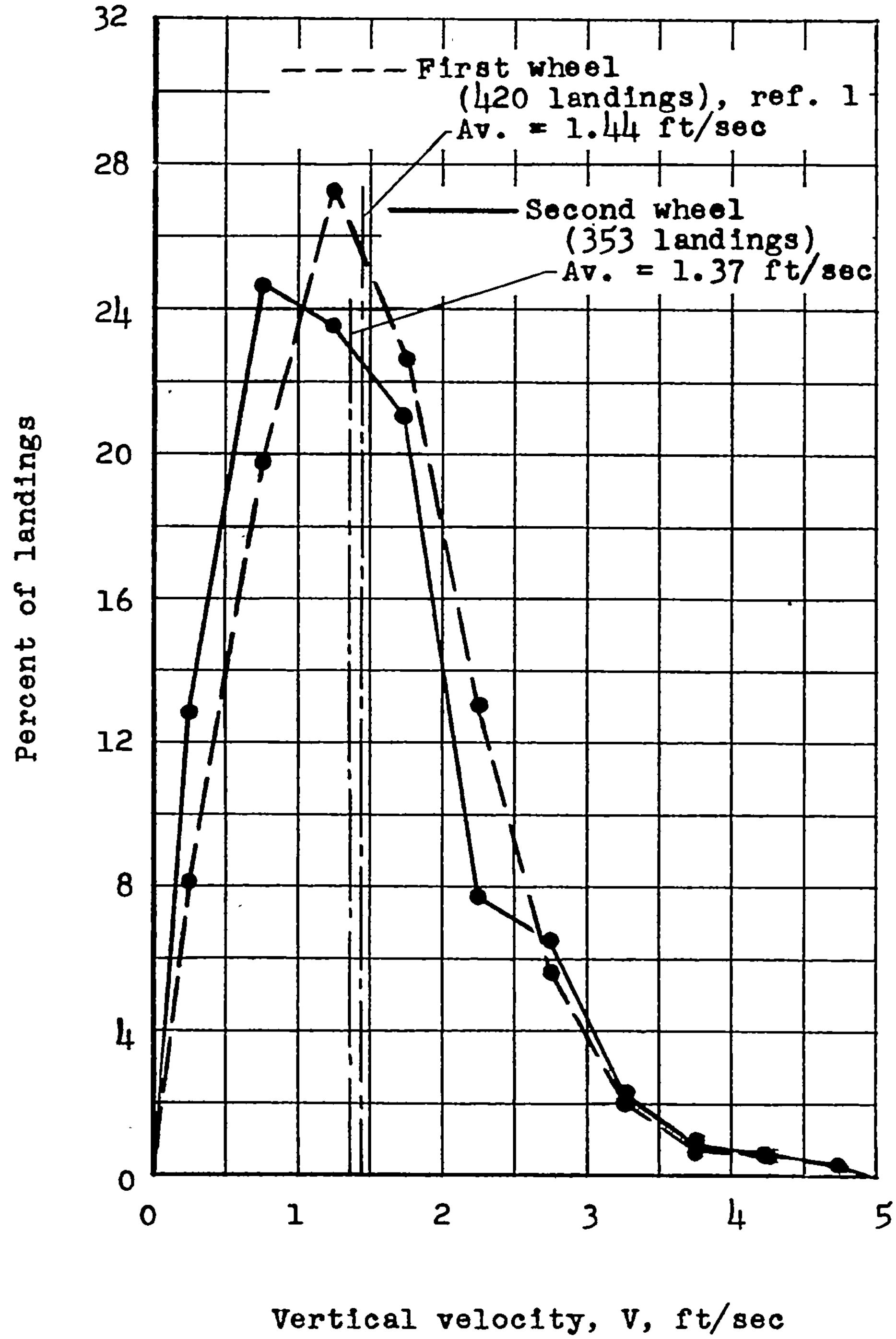


Figure 2.- Frequency distribution of vertical velocities for first and second wheels to contact. Class interval = 0.5.

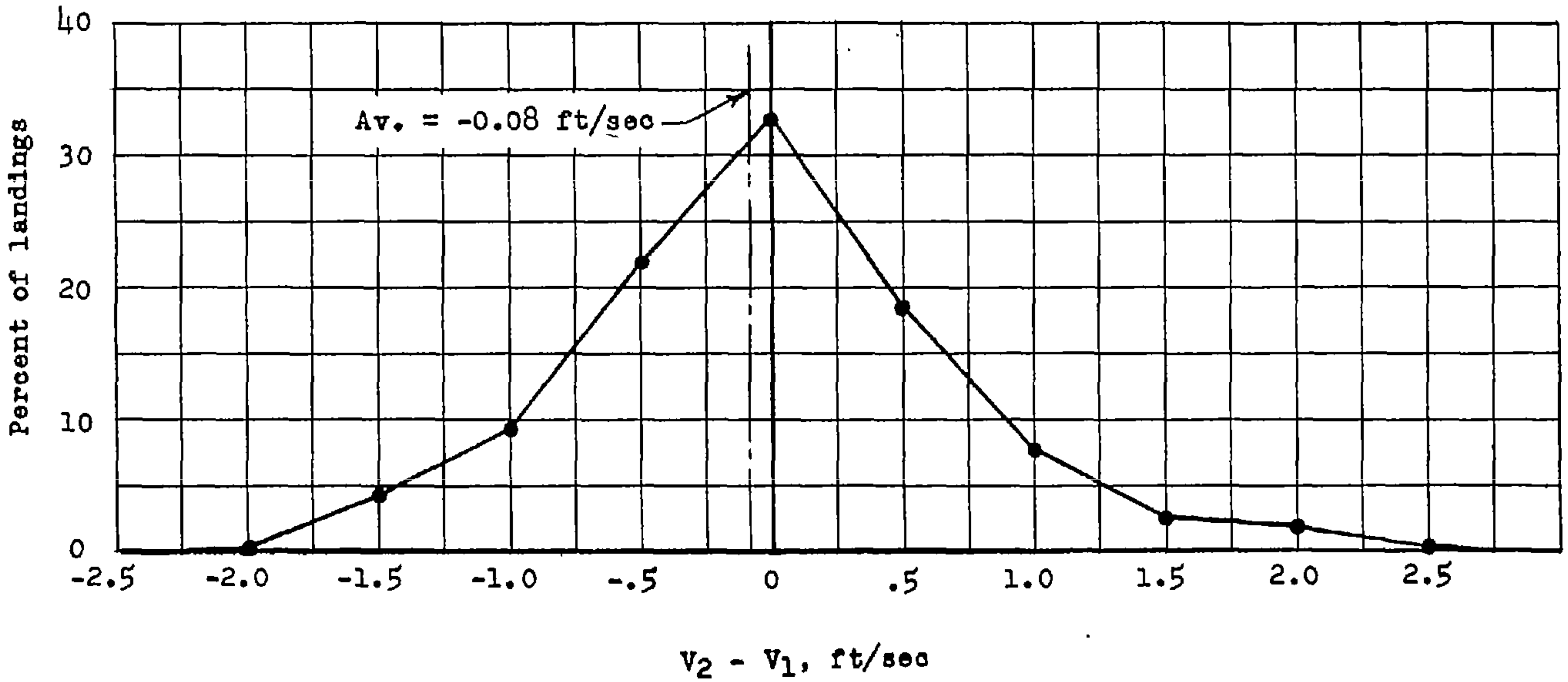


Figure 3.- Frequency distribution of difference between vertical velocities of the first and second wheels to contact. 312 landings; class interval = 0.5.

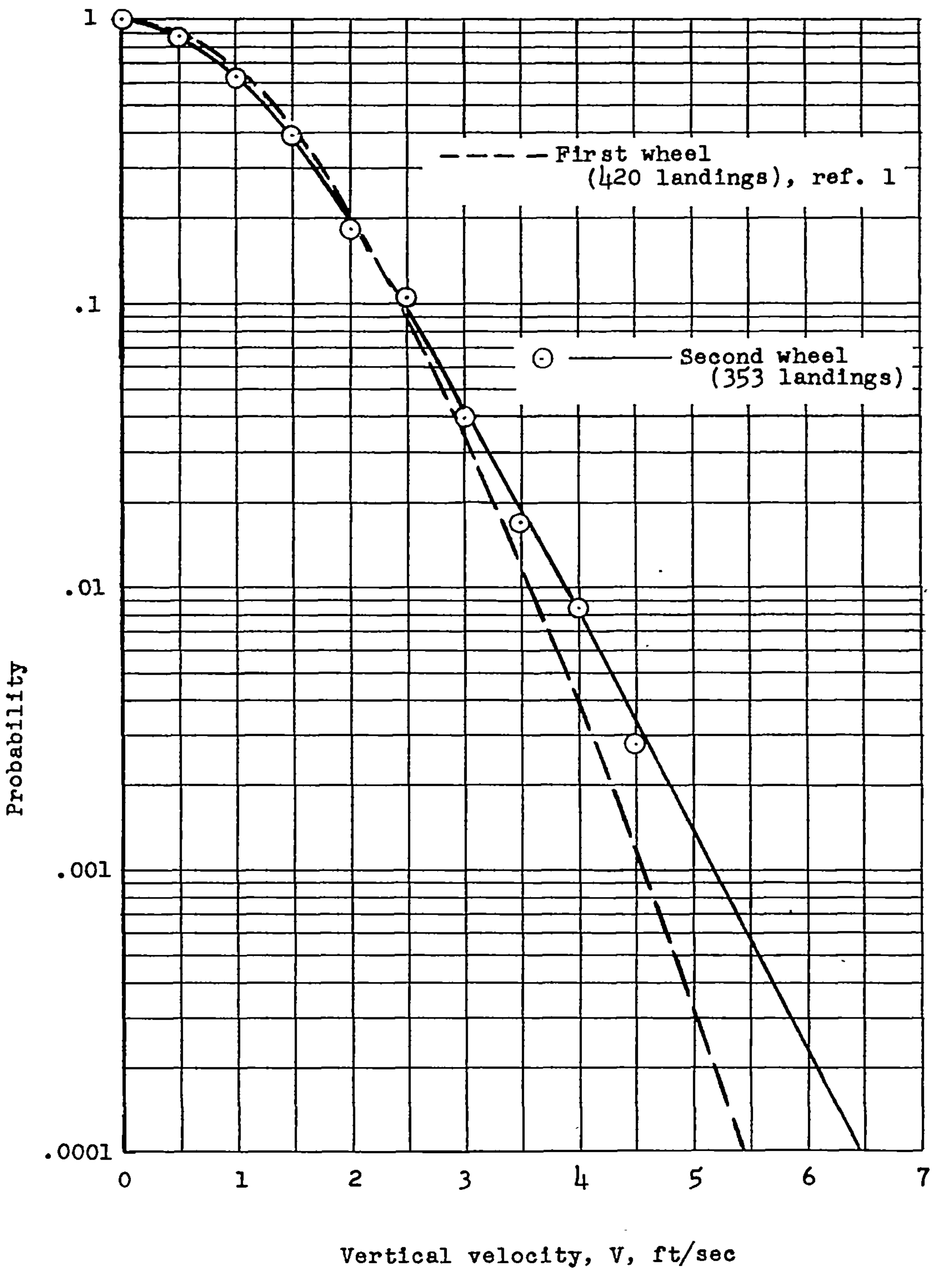


Figure 4.- Probability of equaling or exceeding given values of vertical velocities for the first and second wheels to contact in any given landing.

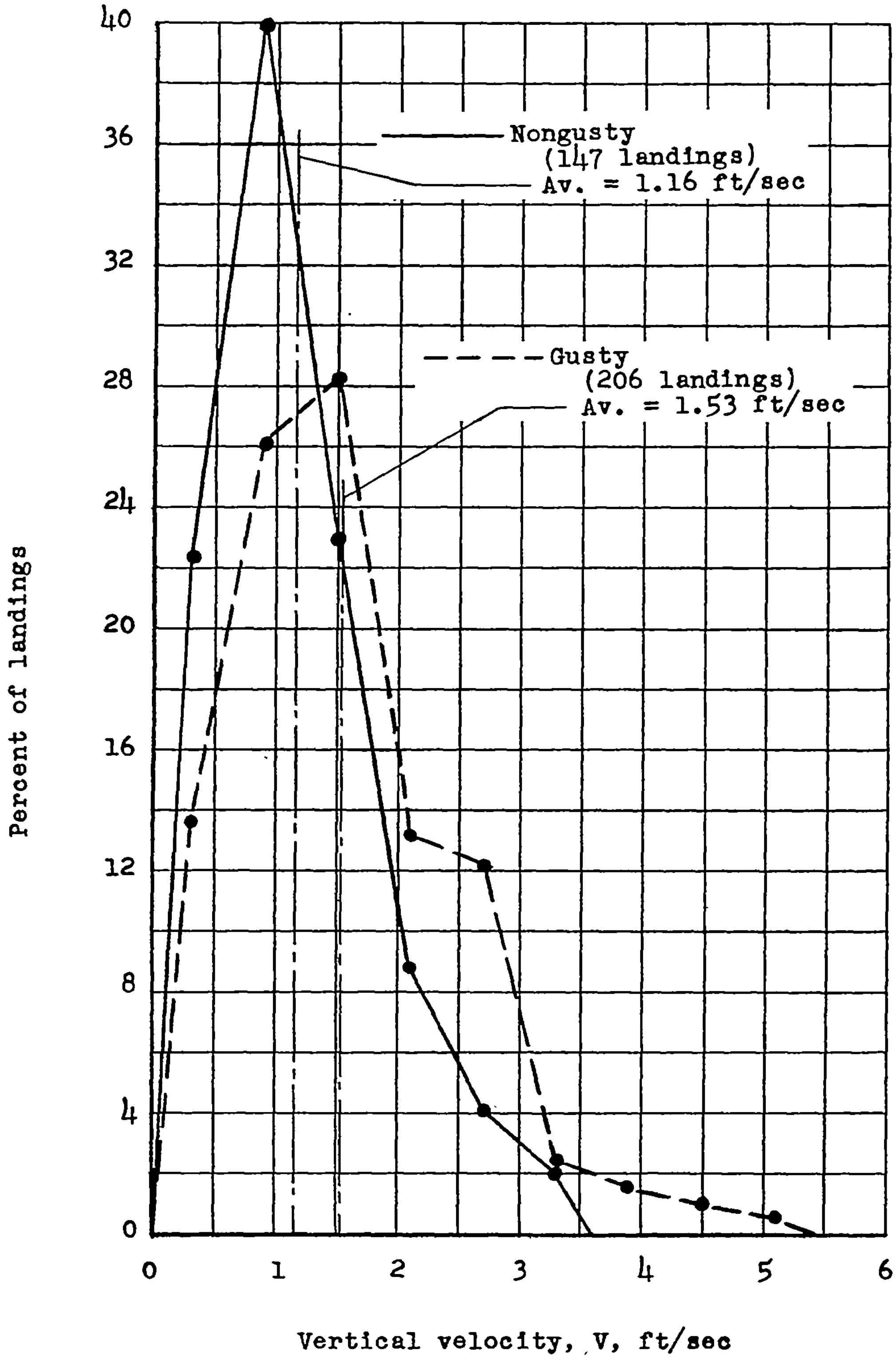


Figure 5.- Frequency distribution of the vertical velocity for the second wheel to contact with and without gusts. Class interval = 0.6.

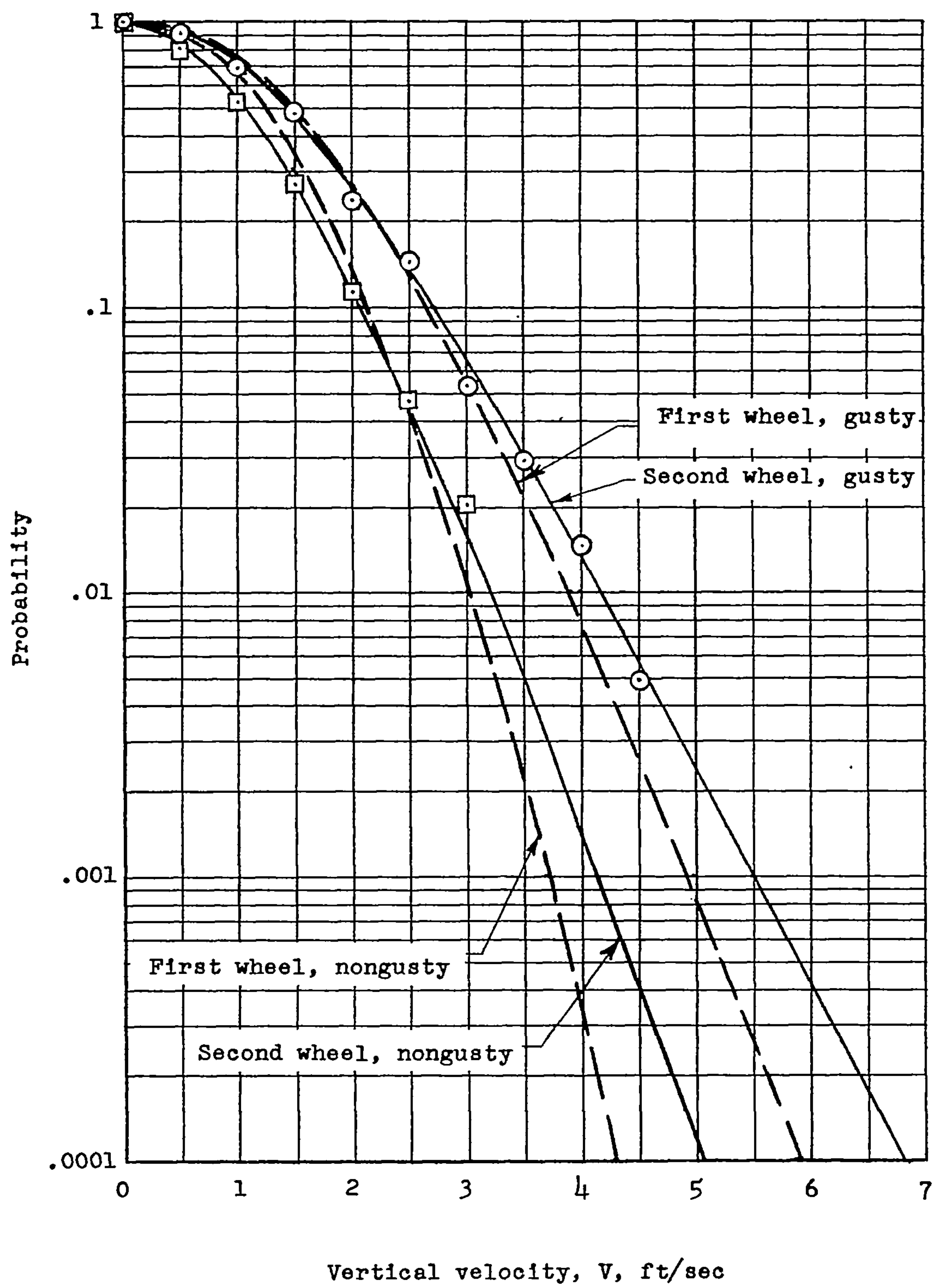
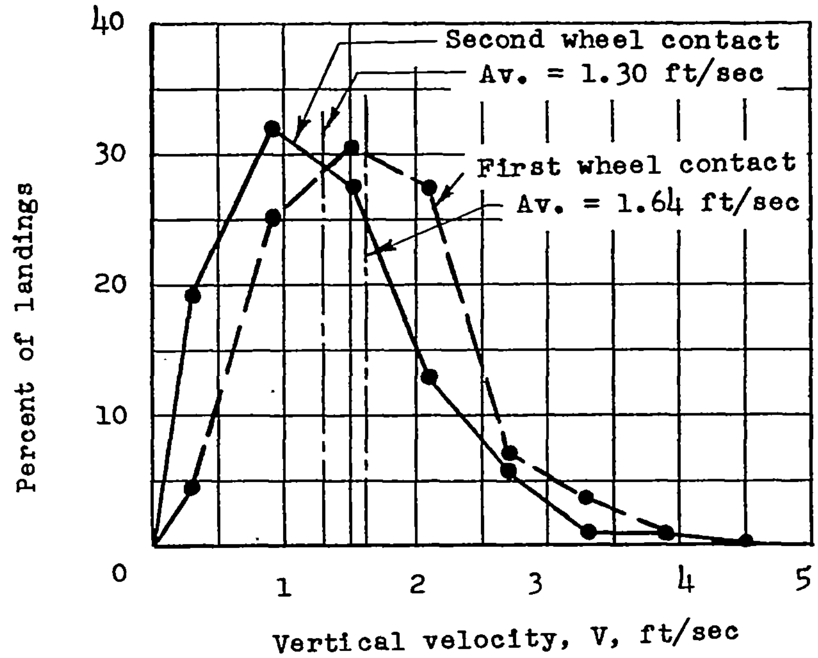
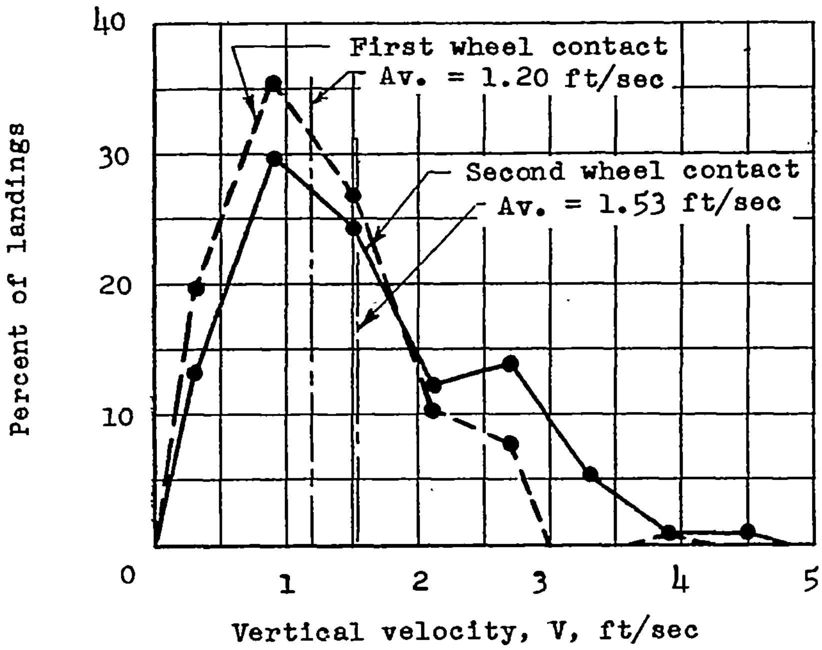


Figure 6.- Probability of equaling or exceeding given vertical velocities for the first and second wheels to contact under gusty and nongusty wind conditions.



(a) Rolling into first wheel to contact (+).



(b) Rolling away from first wheel to contact (-).

Figure 7.- Frequency distribution of the vertical velocities of the first and second wheels to contact with roll toward and away from the first wheel to contact. Class interval = 0.6.

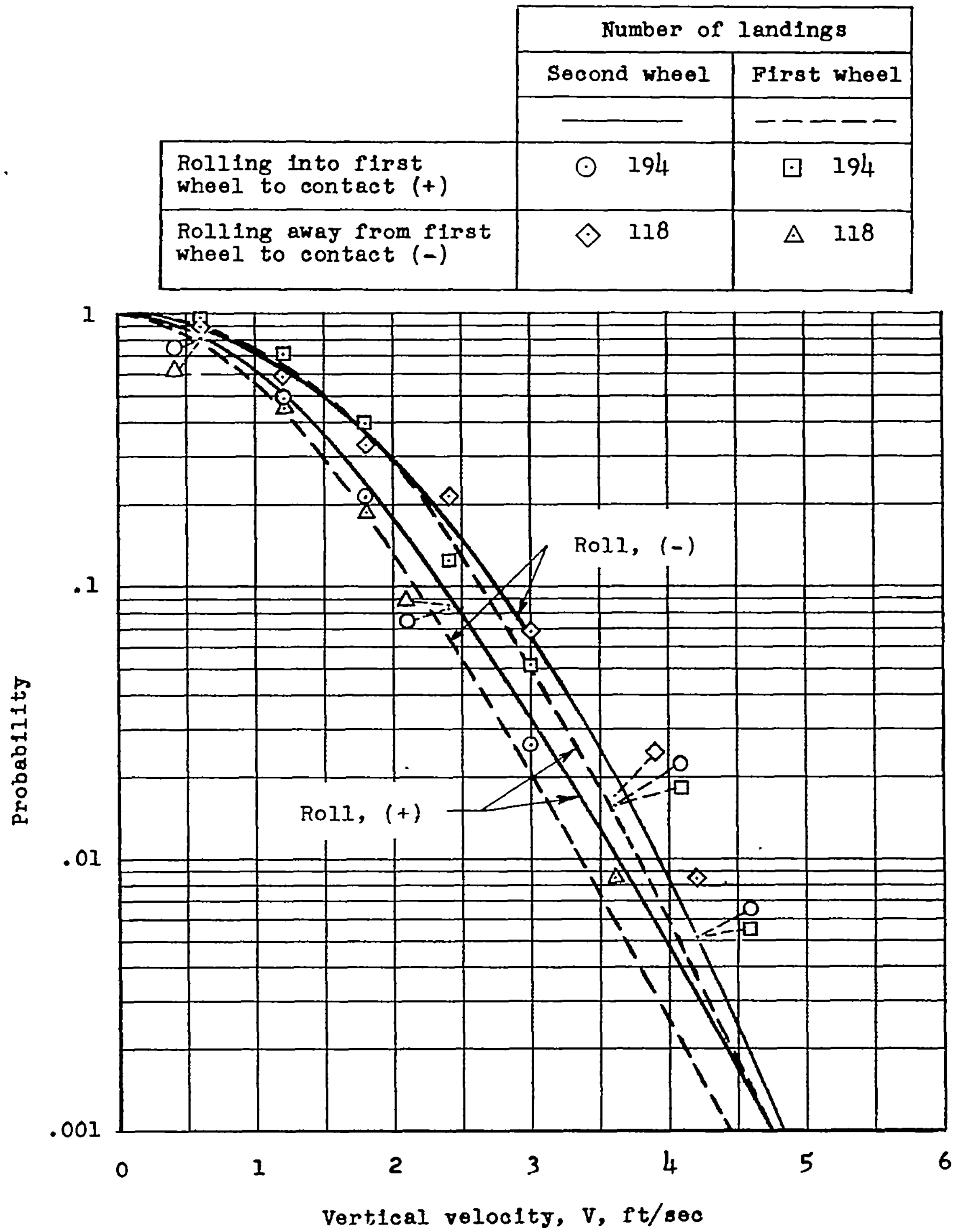


Figure 8.- Probability of equaling or exceeding given values of vertical velocity for the first and second wheels to contact with roll toward and away from the first wheel to contact.

	Number of landings; y_t/k_X range	
	Second contact	First contact
	———	– – – – –
Four engine	132 0.7 to 0.8	132 0.7 to 0.8
Two engine	180 1.0 to 1.2	180 1.0 to 1.2

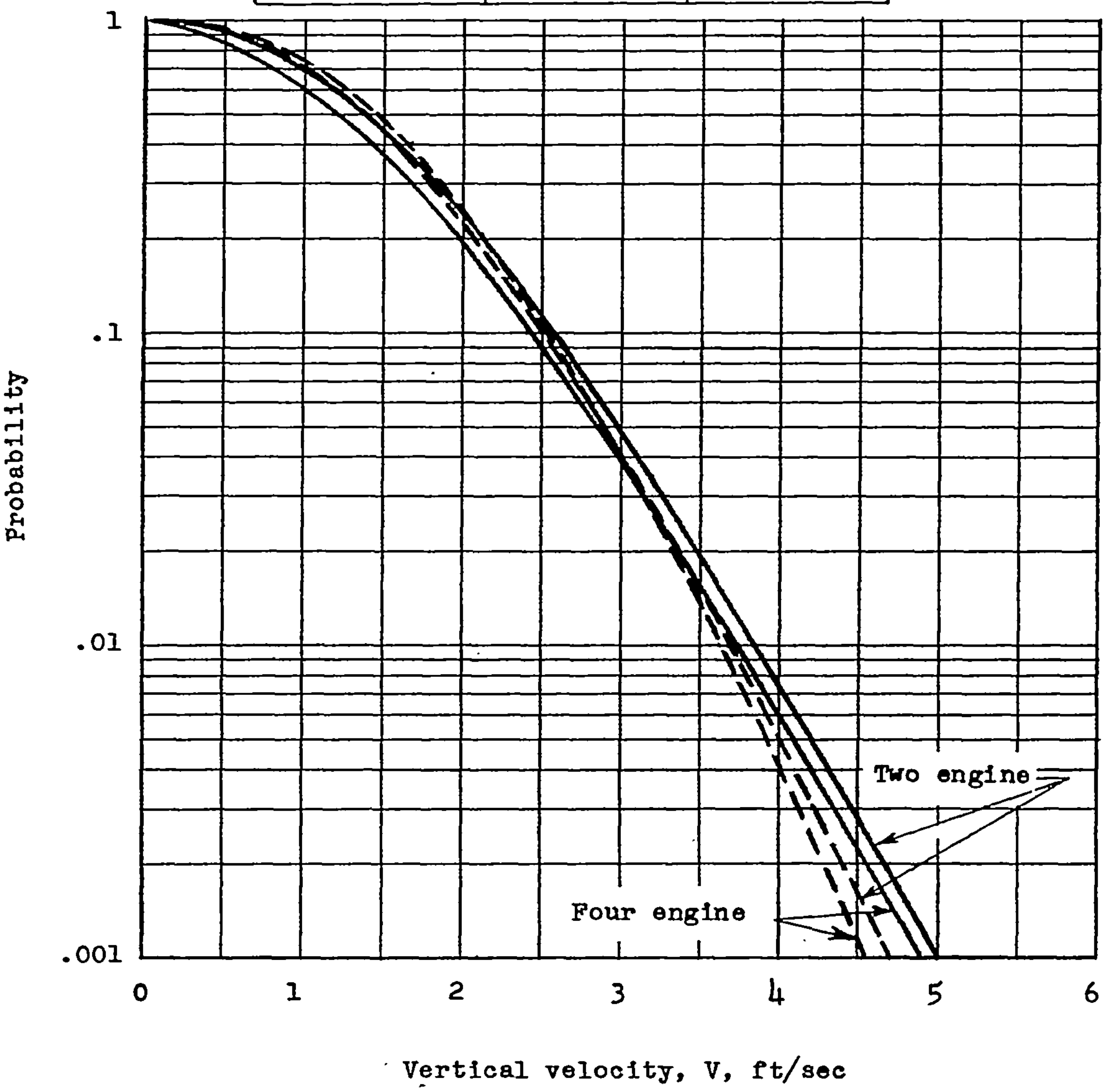


Figure 9.- Comparison of vertical velocities of first and second contact.